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ASTRONOMY
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ASTROPHYSICS
1.2.2008

Discovery of X–rays from the composite supernova remnant G0.9+0.1 with the *BeppoSAX* satellite

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Accepted for publication on Astronomy and Astrophysics Letters

February 1, 2008

Abstract. Using the *BeppoSAX* satellite we have obtained the first secure X–ray detection of the supernova remnant G0.9+0.1. The 1–10 keV spectrum can be described with an absorbed power law with $\alpha \sim 3$ and $N_H \sim 3 \times 10^{23}$ cm^{-2}. The high column density supports a distance similar to that of the Galactic Center. The X-ray emission, with a luminosity $L_X \sim 10^{35} d_{10}^2$ erg s^{-1}, coincides with the central radio core, confirming the composite nature of this remnant. Though a search for periodic pulsations gave a negative result, the observed X–rays are probably related to the presence of a young radio pulsar at the center of G0.9+0.1.

Key words: ISM: supernova remnants: individual: G0.9+0.1 – X–rays

1. Introduction

The radio source G0.9+0.1 was first recognized as a supernova remnant by Kesteven (1968) and later studied in detail with the VLA and the Molonglo Observatory Synthesis Telescope. These observations clearly show that G0.9+0.1 consists of a steep–spectrum radio shell of $\sim 8'$ diameter surrounding a core component with a flatter spectrum and significant polarization (Helfand & Becker 1987; Gray 1994). Thus G0.9+0.1 belongs to the class of "composite" supernova remnants, that, in addition to the radio/X–ray shell formed by the expanding ejecta, show the signature of a central neutron star powering non–thermal emission through the loss of rotational energy (see Weiler & Sramek (1988) for a review of the classification of SNRs into shell–type, plerionic, and composite).

Considering that the formation of a neutron star is expected in most supernovae (Branch 1990), it has been pointed out that plerionic and composite SNR should represent a larger fraction of the known population of SNR than currently observed (Helfand et al.1989). It is not clear whether selection effects, that, especially in the radio band, favour the classification as SNR of shell sources, can entirely account for the observed discrepancy. X–ray observations are playing a crucial role in solving this problem, both through the detection of new remnants (Pfeffermann et al. 1991, Greiner et al. 1994, Busser et al. 1996) and by showing that not all the neutron stars associated with SNR manifest themselves in the radio band as synchrotron nebulae and/or radio pulsars (Mereghetti, Bignami & Caraveo 1996; Petre, Becker & Winkler 1996; Vasisht & Gotthelf 1997).

Until recently, most X-ray observations of SNR have been conducted below a few keV, where interstellar absorption is severe and hampers the study of distant objects in the galactic plane, such as G0.9+0.1. Though the distance of G0.9+0.1 is very uncertain, both the standard Σ–D analysis (Downes 1971, Green 1991), and its location near the galactic center direction, indicate a distance of ~10 kpc or greater. Despite the high absorption along this line of sight ($N_H \sim 10^{23}$ cm^{-2}), the Italian–Dutch *BeppoSAX* satellite, providing imaging capabilities with arcminute angular resolution and good sensitivity also above 4 keV, has allowed a clear detection of the X–ray emission from G0.9+0.1.

2. Observations and Data Analysis

The *BeppoSAX* satellite (Boella et al. 1997a) carries a complement of several imaging and non-imaging X–ray detectors, covering a broad energy range from 0.1 keV to 300 keV. Only the Medium and Low Energy Concentrator Spectrometers instruments are relevant for the results reported here. Both consist of position–sensitive

gas–scintillation proportional counters, placed in the focal plane of the four coaligned grazing incidence X–ray mirrors carried by *BeppoSAX*. The Medium-Energy Concentrator Spectrometer (*MECS*, Boella et al. 1997b) consists of three identical units covering the nominal energy range 1.3–10 keV. Its field of view has a diameter of 56′. The Low Energy Concentrator Spectrometer (*LECS*, Parmar et al. 1997) has a thinner window that allows to extend the low energy response to the range 0.1–10 keV. Both instruments have FWHM energy resolution of $\sim 8.5\sqrt{(6/\mathrm{E})}\%$, where E is the energy in keV.

The location of G0.9+0.1 was imaged during a *BeppoSAX* observation pointed on the SgrB2 molecular cloud. The observation was performed on April 5-6, 1997, and yielded net exposure times of 47 ks for each of the 3 *MECS* units and 19 ks for the *LECS*. Though G0.9+0.1 lies 14 arcmin off–axis, it was clearly detected in the *MECS*, with a total count rate of 0.023±0.002 counts s^{-1}. The centroid of the X–ray emission ($R.A. = 17h\,47m\,22s, Dec. = -28^\circ\,09'\,28''$, J2000) is consistent with the position of the radio core of G0.9+0.1 (Helfand & Becker 1987).

The on–axis angular resolution of the *MECS* is $\sim 2'$ (FWHM), but it degrades to $\sim 3'$ at the source off–axis location. Since the low statistics hampers a more detailed investigation of the source radial profile, to check whether the observed X–ray emission comes from an extended source, we performed the following analysis. The ratio of the net counts within a radius R_1 to those within a corona from R_1 to R_2 centered on the source position was compared to that expected from a point source. The reference data were obtained from ground based calibrations and from a ~ 8 ks exposure of Cyg X–1 at the same off–axis angle. The comparison was done for different energy bands and different values of R_1 and R_2, always giving values compatible with emission from an unresolved source.

The *MECS* counts used in the spectral analysis were extracted from circular regions of 4′ radius, and the 256 original channels were grouped in order to have at least 20 net counts in each energy bin. The background spectrum was derived from a source free region of the same observation.

The spectrum is well fit by a simple power–law model, giving a reduced $\chi^2 = 0.95$ (42 d.o.f.) for photon index $\alpha = 3.1$, $N_H = 3.0 \times 10^{23}$ cm^{-2}, and flux $F = 2.12 \times 10^{-11}$ erg cm^{-2} s^{-1} (1–10 keV, corrected for the absorption). Acceptable fits were also obtained with blackbody and thermal bremsstrahlung spectra (see Table 1), while a Raymond-Smith thermal plasma model with abundances fixed at the solar values gave a worse result. There is no evidence for lines in the X-ray spectrum. In particular, we can set an upper limit of 400 eV (90% confidence level) on the equivalent width of Fe K lines.

The luminosity corresponding to the best fit power–law spectrum is $L_X = 2.4 \times 10^{35} d_{10}^2$ erg s^{-1} in the 1–10 keV range, but note that some uncertainty on this value is introduced by the relatively poorly constrained spectral parameters (see Table 1). This is particularly evident for the power–law case ($[0.8 \times 10^{35}, 1.6 \times 10^{36}]\ d_{10}^2$ erg s^{-1}), while the luminosity uncertainty is smaller for the other models.

G0.9+0.1 was also detected in the *LECS* instrument, but only above ∼2 keV, due to the high interstellar absorption. We verified that the inclusion of the *LECS* counts in the spectral fits does not significantly change the results described above.

The same counts extracted for the spectral study were used for the timing analysis, after the correction of their times of arrival to the solar system barycenter. No flux variations were seen during the *BeppoSAX* observation. A search for pulsations for periods in the range 8 ms to 2048 s gave a negative result. With the hypothesis of a sinusoidal modulation, we can set the following upper limits on the pulsed fraction: 53% for 8 < P < 16 ms, 38% for 16 < P < 32 ms, and 33% for P > 32 ms.

3. Discussion

Thanks to the *BeppoSAX* good sensitivity above a few keV, our observation has provided the first firm evidence of X–ray emission from G0.9+0.1. Though this region of sky has been imaged in the past with other X–ray satellites, only a very marginal and uncertain detection of G0.9+0.1 was reported by Helfand & Becker (1987), based on an observation done with the Imaging Proportional Counter (IPC) on the Einstein Observatory in 1979. The claimed detection of a source with 0.009±0.003 counts s^{-1} at more than one arcminute west of the SNR center, was based on a rather *ad hoc* procedure aimed at maximizing the very small number of net counts and on an uncertain background estimate. Reanalysing the same IPC pointing (5 ks), we found no sources above a signal to noise ratio of 2, inside the region corresponding to the radio SNR. With these data we can only put an upper limit of 0.03 counts s^{-1}, while the expected IPC count rate, based on our best fits, is only of $\sim 10^{-3}$ counts s^{-1}, one order of magnitude below that reported by Helfand & Becker (1987).

A search in the ROSAT public archives yielded several PSPC and HRI observations containing the position of G0.9+0.1. However, due to the short exposure times of only a few thousand seconds and especially to the high absorption in the ROSAT band, the SNR was not detected.

All our spectral fits give values of N_H greater than 10^{23} cm^{-2}, indicating that G0.9+0.1 must be at a distance of several kiloparsecs, probably close to the Galactic Center or even beyond it. In the following discussion we shall assume a distance of 10 kpc. The large interstellar absorption also explains the apparent discrepancy between our derived luminosity of a few 10^{35} erg s^{-1} and the smaller one estimated by Helfand & Becker (1987), who assumed a lower N_H value for the IPC count rate to flux conversion.

Table 1. Results of the Spectral Fits (errors are 90% c.l.).

Model	Column density (10^{22} cm^{-2})	Parameter	Red. χ^2	Flux (1–10 keV) (10^{-11} ergs cm^{-2}s^{-1})
Power law	$30.3^{+14.7}_{-10.3}$	$\alpha = 3.1^{+1.4}_{-1.1}$	0.95	$2.1^{+12}_{-1.4}$
Bremsstrahlung	$25.6^{+4.4}_{-5.6}$	$T_{\rm br} = 4.3^{+6.7}_{-1.3}$ keV	0.96	$0.94^{+0.40}_{-0.32}$
Black body	$17.9^{+7.1}_{-7.9}$	$T_{\rm bb} = 1.4^{+0.5}_{-0.3}$ keV	0.98	$0.42^{+0.24}_{-0.10}$
Raymond-Smith	$13.6^{+6.4}_{-3.6}$	$T_{\rm RS} = 31^{+\infty}_{-16}$ keV	1.22	0.45

The peak of the X–ray emission is coincident with the SNR radio core and there is no evidence for a spatial extension greater than the instrumental resolution. Were the X–rays emitted from a shell with the same dimensions observed in the radio band (diameter $\sim$ 8 arcmin), they would appear clearly resolved in the $MECS$ images. Therefore, we are clearly seeing X–rays emitted predominantly from the central region of the remnant, either from a point source or from a nebula with radius smaller than $\sim$ 2 arcmin.

Some SNRs, like for example W44 (Rho et al. 1994), present a centrally peaked X–ray emission of thermal origin. The thermal nature of the emission is clearly demonstrated by the detection of lines in their X–ray spectra. All the SNRs of this kind have a limb-brightened radio morphology without a flat–spectrum core, contrary to the case of G0.9+0.1. Also considering that the thermal plasma model gave the worst fit to our data, we favour the alternative interpretations related to the likely presence of a neutron star at the center of G0.9+0.1.

One possibility is that of thermal emission from the neutron star surface. The results of the blackbody spectral fit imply an emitting surface with radius $R = 0.3^{+0.4}_{-0.2} d_{10}$ km, definitely smaller than the whole neutron star surface for any reasonable distance. This can be interpreted as emission from a small polar cap region, hotter than the rest of the neutron star due to anisotropic heat diffusion from the interior and/or to reheating by relativistic particles backward accelerated in the magnetosphere (Halpern & Ruderman 1993). In general, this should produce a periodic flux modulation, but the strong gravitational bending effects severely reduce the observed pulsed fractions (Page 1995). Our upper limits on the possible flux modulations are not strong enough to pose serious problems to this interpretation. However, the fitted blackbody temperature (kT$\sim$1.4 keV) is higher than that observed in all the other X–ray emitting radio pulsars.

A different explanation involves non-thermal emission powered by the rotational energy loss of a relatively young neutron star. The radio shell radius of $\sim$12 pc implies a lower limit to the remnant age of $\sim$1100 yr, for a free-expansion phase with v$\sim$ 10^4 km s^{-1}. If the remnant is expanding adiabatically, from the Sedov model we have a shell radius $R \sim 14(E_{51}/n_o)^{1/5} t_4^{2/5}$pc, where E_{51} is the explosion energy in units of 10^{51} ergs, n_o is the ambient ISM hydrogen density in cm^{-3} and t_4 is the age in units of 10^4 yr. For typical values $(E_{51}/n_o)^{1/5} \sim 1$, we derive an age of $\sim 6,800$ years. Both a point–like, pulsed component originating in the neutron star magnetosphere and a diffuse $(1-3')$ synchrotron nebula probably contribute to the observed X–rays.

Our best fit power law photon index 3.1 is rather steep, compared to other X–ray synchrotron nebulae, but a more typical value of $\alpha = 2$ is also consistent with our data (for $N_H = 2\times10^{23}$ cm^{-2}). The corresponding X–ray luminosity (1-10 keV), $L_X = 8.2\times10^{34} d_{10}^2$ erg s^{-1}, is within the range observed in the central components of other SNRs (see, e.g., Helfand & Becker 1987) and can be easily powered by a young neutron star.

4. Conclusions

With the *BeppoSAX* satellite we have discovered X–ray emission from the central region of the supernova remnant G0.9+0.1 located close to the Galactic Center direction. The high interstellar absorption is consistent with a distance of the order of 10 kpc and, correspondingly, an X–ray luminosity of $\gtrsim 10^{35}$ erg s^{-1}.

Although we cannot completely rule out a thermal origin of the X–ray emission, its small angular extent (radius $\lesssim 2'$), the good fit with a power-law, the presence of a flat spectrum radio core, and the estimated SNR age of a few thousand years, favour the interpretation in terms of synchrotron emission powered by a young, energetic pulsar.

Acknowledgements. We thank Lucio Chiappetti and Silvano Molendi for useful discussions and help with the data analysis.

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